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SOLAR BOX COOKERS: TOWARDS A DECENTRALIZED SUSTAINABLE ENERGY STRATEGY FOR SUB-SAHARAN AFRICA

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Abstract—The continued economic decline of sub-Saharan Africa, and the African energy crisis in particular, have received considerable attention in recent literature. Little attention, however, has been given to the assessment of solar power as an environmentally sound and economically viable energy strategy. Considering the increasing fuelwood scarcity and debt incurred through petroleum imports, solar energy provides a welcome alternative to traditional biomass and fossil fuel energy sources. Research and development in solar energy has concentrated primarily on highly technical, capital intensive applications, leaving possibilities for small scale utilizations unexplored. This paper argues for small scale, decentralized development of solar power as a sustainable household fuel source for sub-Saharan Africa. Domestic cooking constitutes more than 60% of total energy use in the region and consumes scarce time, labor, income, and natural resources. Thus, the appropriate management of fuel and energy resources in the residential sector is crucial for significant development. This paper examines the economic viability of solar box cookers (SBCs), their costs and benefits both on the household and community levels, and how they may contribute to economic development. In arguing for the implementation of SBCs, policy implications in terms of financing and a comprehensive energy plan geared towards sustainable development are also presented. © 1998 Elsevier Science Ltd. All rights reserved

ECONOMIC DECLINE IN THE SUB-SAHARAN AFRICAN REGION

As the twentieth century draws to a close, we recognize the limits of the world's resource base and the damaging effects that traditional growth policies have had on both natural and human resources. Although definitions of sustainable development vary, implicit in them is the link between environmental survival and economic success. Long-term net social benefits which consider intergenerational equity are increasingly seen as dependent on the preservation and efficient utilization of present natural resources. True least cost planning methods and models which adequately consider externalities are gaining attention

among economists, and are changing perceptions regarding the legitimate economic value of renewable energy sources and ecological capital.[1]

The development crisis in Africa, characterized by negative growth rates, population explosion, reduction in per capita agricultural production, large foreign debts, and environmental degradation provides a significant challenge to traditional economic growth models and an opportunity for implementation of new sustainable development policies. Despite possession of the resources required for development, the majority of Africans live in poverty, and their economies comprise 28 of the world's poorest. During the 1980s, six more African countries fell into the low-income category classified by the World Bank, while the overall sub-Saharan African debt mounted to US$250 billion, almost equal to the region's GNP.[2] Whether this crisis is due to primarily exogenous neocolonial exploitation through unequal terms of trade, or to endogenous structural factors and government failure, African lack of success in achieving its development goals can be attributed to the manipulation of power by elite groups and dependency upon foreign technology and finished goods. Development projects often fail to aid their proclaimed beneficiaries and serve only to expand state bureaucratic control. Administers of the state and the international development assistance apparatus reap the financial benefits of development as project management is channelled away from communities and towards these officials.[3] Therefore, a revised development strategy is necessary which promotes participatory, democratic, grassroots action and relies on indigenous materials and appropriate technology. Moreover, ecological sustainability must be taken into account and given long-term economic value as the ultimate provider of all people's basic needs. This is consistent with economic interpretation of sustainable development—the path that maximizes the long-term net benefits to humankind.

ENERGY SITUATION AND FUELWOOD CRISIS

Well-formulated, efficient energy programs comprise an essential element of a comprehensive economic development strategy. As the populations of African countries continue to grow, the demand for sufficient, reliable energy expands with them. According to a recent estimate, the energy growth rate in developing countries is likely to run at 5–6% while in a global context it is stabilizing at 1.5–2.5%.[4] As economies evolve, the demand for energy increases and then declines as sources are utilized more efficiently. The task for developing countries is to minimize the amount of energy necessary for economic growth and to reduce the time frame between energy demand peaks and subsequent decline.[5] The energy situation of Africa poses complex difficulties for planners because of the absence of organized national energy development strategies, limited local and external financial resources, and shortage of skilled labor.[6] Given that roughly 85–90% of African people live in rural areas, the focus on rural energy programs is highly desired. However, rural isolation from electrical transmission grids and poor infrastructure pose further problems in rural energy management and development.[7]

As a result, while countries such as Botswana, Angola, Zambia and others maintain vast reserves of coal and renewable energy potential, their industrial and commercial sectors continue to rely on petroleum imports, and the vast majority of citizens depend on non-commercial biomass fuels for household consumption. Consumption patterns have been well documented in recent literature, showing woodfuel to represent 70–95% of the total energy use in sub-Saharan Africa. The bulk of energy is unanimously consumed by the

residential sector. In Ghana, wood and petroleum constitute 80 and 13% of the country's average annual energy supply respectively, which is overwhelmingly consumed by households (77%).[8] Similarly, in Kenya, over 70% of energy resources are comprised of wood and other traditional biomass fuels. Tanzania relies on fuelwood for 92% of energy consumption, 85% of which is consumed within the household sector.[9] Despite efforts in the 1970s and 1980s to direct the energy balance away from traditional fuels and towards commerical fuels (both coal and oil) in some countries, success has been minimal.[10] Over 60% of this total energy consumption is on domestic cooking alone.[11]

The reliance on petroleum imports and the heavy dependence on traditional fuels hinders development in several ways, which have gained attention in recent literature. Oil imports aggravate the balance of payments crisis of most sub-Saharan African countries and increase their foreign debt, preventing sustainability and self-reliance. The heavy consumption of wood resources by both growing urban and rural populations has contributed to the deforestation and desertification of many areas. In an extreme case, only 1.4% of the original wood-lots in Eritrea remain,[12] and in many areas, forests are harvested much more quickly than they can regenerate. In addition to the loss of ecological capital and biodiversity which provide a significant national economic resource, deforestation leads to fuelwood scarcity, especially around urban areas. These shortages contribute to increased costs for households as they must buy non-local wood and other fuels for cooking, or are forced to expend more labor time in searching for fuelwood. Long hours spent gathering wood takes away time from productive activities. Furthermore, cooking with wood often contributes to respiratory diseases in women and children, leading to decreased productivity, greater expenditures in health care, and the loss of human lives. On a global level, burning of wood and biomass fuels contributes 35–40% of the carbon dioxide and other greenhouse gas emissions which cause global warming.[13] Clearly, the development of renewable indigenous energy sources as alternatives to biomass fuels is required for community and regional development.

SOLAR POWER—AN ALTERNATIVE ENERGY

Among other renewable energy sources, solar energy has enormous potential for alleviating dependence on oil imports and contributing to a sustainable development process in sun-rich Africa. In the past two decades, some progress has been made in implementing solar applications such as solar generators, solar stills, water heaters, crop dryers, and large scale photovoltaic devices for lighting, rural telephones and refrigeration. In a norther Ghanaian hospital, for example, a solar steam autoclave for instrument sterilization, two photovoltaic systems as emergency lighting systems, and a solar washing system for washing machines were installed, proving to be useful and efficient.[14] Botswana has incorporated use of solar energy in its National Energy Master Plan, and has implemented multiple solar applications. These applications include: solar water heating for domestic and commercial uses, solar desalination, passive solar buildings for indoor climate control, photovoltaic devices for lighting, water pumping, communication, and fence electrification.[15] However, success in the dissemination of solar energy thus far has remained limited. Despite rapid growth in the consumption of solar energy in Botswana, for example, the use accounted for only 0.05% of total energy in 1989, and is expected to increase to a mere 0.11% by the year 2010. Reasons for the lack of solar development are multifaceted, but lie primarily in the historical character of development assistance projects in the 1960s, 1970s and 1980s

which did not focus on renewable energy development, especially after oil prices collapsed in the mid 1980s. Instead, state and international programs have focused on centralized, large-scale hydro projects, petroleum products, and development of fossil-fuel burning plants that were highly capital intensive. Government efforts are often geared primarily to strengthening the national utility companies, which discourage private sector small-scale development of renewable resources.[16] These energy programs tend to benefit urban areas and to mirror the industrialization strategies taken by developed countries. Such a route has been advocated by the development apparatus, with an emphasis on highly technical, large-scale projects. Previous solar research and development have operated according to this emphasis, promoting capital intensive, technologically advanced applications which require highly skilled professionals and developed infrastructure for dissemination and maintenance. As a result, solar energy has remained under state bureaucratic and international expert supervision, and has had limited success in improving the lives of African masses.[17]

In recent years, however, projects embracing the grassroots participatory strategy for development have promoted the research, development, and dissemination of solar box cookers (SBCs) in Africa. Simple ovens constructed with wood or cardboard, glass, aluminum foil, and silicone caulk, SBCs are relatively capital non-intensive, and can be easily built and maintained by individuals with little or no technical training. The number of solar oven projects has risen dramatically in the past 5–10 years, as has international funding for these projects. From 1988 to 1991, the number of promoter groups increased threefold, from 20 to 60 international NGOs, and this number continues to grow.[18]

Currently within Africa, programs involving dissemination of solar ovens exist in Senegal, Mali, Sierra Leone, Sudan, Eritrea, Zimbabwe, Kenya, Tanzania, South Africa, Lesotho, and elsewhere. Workshops sponsored by NGOs, national universities, girl scouts, government agencies and local firms have taught thousands of people to build and cook with SBCs. The mass production of SBCs has been initiated in Tanzania and South Africa.[19] The moderate success of projects in face of the radical innovational nature of solar cooking is encouraging. In a 1994–95 study conducted in Zimbabwe, 82% of the participants in a SBC educational project held in 1989 still used their solar ovens. Of these, 71% claimed that they used their cooker most sunny days. Less positively, 52% reported using their oven less this year than last.[20] Although in a survey of 100 other projects, rates of adoption have sometimes been less successful, on average solar ovens replace the use of 50% of traditional cooking fuels.[21]

ECONOMIC ASPECTS OF SOLAR BOX COOKERS

In addition to bureaucratic and political obstacles, the limited success of SBC dissemination projects can be attributed to the fact that the purchase of an SBC constitutes a significant capital investment for most rural and urban poor households. Although the process of solar cookers vary depending on the prices of local materials and type of production (whether by mass production, volunteer trainees, or the individual herself), the range is generally from 20 to 40 US$.[22] In Kenya, for example, the materials for a durable wooden solar oven cost less than 30US$. Although this appears high in a low-income nation where per capita income averages 400US$, cost of the one-time investment pales to the 30–40% of household income that is usually spent on wood and charcoal fuels annually (around 140US$).[23] Although people of some rural areas are still able to obtain enough

fuelwood free of cost, this is becoming exceedingly rare as woodlots diminish. Solar ovens have become more economical in many areas as the prices of fuelwood have increased due to heavy deforestation and due to local scarcities of other fuels such as kerosene and liquid petroleum gas (LPG).[24] The price for fuelwood is dependent on the prices of other fuels, as it follows the theoretical break-even price ratios of various household fuels per unit relative to fuelwood. As costs for electricity and other fuels increase, they push up the price for fuelwood as well.[25]

In light of this energy scenario, SBCs are well capable of supplying energy demand in African rural and poor urban household sectors. Appendix 1 compares the cost and efficiency of alternative cooking technologies. SBCs achieve a significantly higher efficiency rate than all of the traditional fuel systems. Although in a traditional system there is no capital cost for the stove itself, the annual costs for fuel either as a percentage of family income or in terms of labor hours used to procure fuel far exceed the initial capital cost of an SBC. Despite the increased efficiency in liquid gas and electric stoves, here again, one must consider the relatively high cost and low availability of kerosene, gas, and electricity in the rural areas of African countries where most people live, in addition to the capital cost of the stove. If these factors are considered, the SBC proves to be an economically viable alternative to most kinds of stoves.

In calculating the net present value of SBCs, Kandpal and Mathur (1986) elaborate the factors which affect the economic feasibility of SBCs for households.[26] The number of meals that the user can cook in a year with the SBC and the amount of energy saved per cooked meal determine the success of the system. The number of meals cooked per year is influenced by the design of the cooker and the types of food cooked in the region. The value of energy saved is dependent on the price of conventional fuels and the resulting cost of fuel saved by SBC use. In evaluating the number of meals necessary to balance the initial investment considering three different costs of conventional fuels, the authors determine that the single most important factor affecting the economics of the solar cooker is the price and availability of conventional fuel per meal. If the amount of money saved by using the solar cooker instead of conventional fuel is little enough to where the cooker only becomes economic after a great number of meals, people will be less willing to make the initial investment. Cheap solar cookers that use local resources and indigenous technology can reduce costs considerably. Governments may provide adequate subsidies and interest-free loans to poor households in order to reduce the cost of the SBC thereby inducing households to buy solar cookers.

A 1994–1995 study in Zimbabwe illustrates this correlation between the amount of fuel saved and acceptance rates of SBCs.[27] Of the 155 participants in the project—71% reporting that after five years they still used their SBCs most sunny days—over half reported that solar cooking saved about half (26% of participants) or more than half (26% of participants) of conventional fuel. An additional 30% said that SBCs saved "a little bit" of fuel.[28]

In addition to the economic efficiency aspects which affect the adoption rate of SBCs, the importance of socio-cultural factors and power relations within households must not be overlooked when determining dissemination policies.

FINANCING SOLAR COOKERS

The availability of subsidies for solar cookers affects their adoption rate. The Zimbabwean study showed a correlation between the demand for further workshops and the

need for subsidies provided by these workshops. Although people within the community were skilled in SBC construction and could easily teach it to their friends, the use of SBCs did not increase beyond initial participants. People who were asked why they did not build an oven themselves responded that they did not have money for materials. This justification suggests that subsidies are highly desirable for dissemination success.

In light of the balance of payments crisis that plagues African economies, further government spending on subsidies is difficult, and not necessarily desirable. Realistically, because SBCs have few immediate, pronounced effects on production, subsidies would be difficult to justify to governments who seek wealth in the short term and look to high-profile, technocratic development projects in the industrial urban sector. Other creative finance methods are possible, however, such as one similar to the Grameen Rural Bank group lending scheme of Bangladesh, where credit is given directly to groups of rural women for entrepreneurial projects.[29] This system has an extraordinary repayment rate, with 97% of loans repaid in the first year, and 99% within 2 years. In a similar manner, funds could be allocated to groups of women to buy the materials for several solar cookers, thereby taking advantage of economies of scale. The money saved on fuel expense could be used to repay the loan. "Layaway" plans provide another alternative, where small payments are made towards a finished solar cooker. This method would be similar to conventional spending on fuelwood and would operate within traditional budget constraints. In any case subsidies or payment programs will be necessary until a rise in income allows households to move to a new budget line and be able to afford the SBCs outright. Furthermore, legal restructuring of credit programs is necessary to ensure poor women's access to lending institutions. In most areas of Africa, women (and the rural and urban poor in general) suffer barriers to credit access. Since cooking falls into the domain of traditional women's work, it cannot be expected that men will recognize the value of SBCs. Therefore, women must have their own opportunities for financing these capital costs.

SOLAR COOKING AND ECONOMIC GROWTH

The development of solar cooking has positive implications for the industrial sectors of indigenous economies. Unlike fuelwood which merely depletes ecological capital without positive effects on local production, SBCs boost local businesses and create backward and forward linkages via the multiplier effect. The use of nails stimulates local hardware and metal businesses, the glass and aluminum promote production in these areas, and the wood boards advance the carpentry and timber industries. Increased production generates employment opportunities. Therefore, these spillovers help to create a healthy local economy that is based on indigenous resources.

By not turning to petroleum-based energy sources for fuelwood replacement, African countries restrain their already high oil imports which they purchase with export earnings. Ethiopia, for example, spends 35% of its export earnings on petroleum imports.[30] These export earnings could be put to much more productive use, whether through national investment in development projects or the purchase of computer technologies etc. Moreover, a decrease in imports leads to an increase in net exports, and thus of aggregate demand. Since aggregate demand equals national income, this translates into a growth in output and national income. In time, this growth leads to self-sustainable development which is based on the improvements in quality of life for all Africans rather than those few who benefit from petroleum imports.

WOMEN, HOUSEWORK, AND THE SBC ADVANTAGES

The Structural Adjustment Programs (SAPs) and macroeconomic stabilization of the 1980s and 1990s attempted to alleviate the balance of payment crises and to encourage foreign investment in African countries. These policies initiated by the World Bank and the IMF dictate reductions in government spending, promotion of exports, privatization, price reforms, and deregulation of markets.[31] That the strain of adjustment has fallen unevenly upon poor women and children has been well-documented in the WID (Women in Development) literature.[32] As governments tighten their purse strings, social provisioning is cut, and families are required to pay school fees and health care costs that were previously subsidized. The pricing deregulation leads to an increase in food prices which are usually accompanied by a too slow supply response to warrant wage increases. Rural and urban poor women, as workers in the home and subsistence farmers experience increased demands on their time as they are forced to work longer hours in informal sector jobs to pay for food, taxes, fees, and other services. This leads to a deterioration in both women's and children's welfare, and a resulting loss in human capital, which is fundamental for economic development.

In addition to saving household income, SBCs are labor-saving devices that decrease demands on women's time, can reverse the negative impacts of SAPs, and promote long-term increases in productivity and economic development. Currently, the majority of African women spend vast amounts of time gathering fuel. From an estimate of the early 1980s, an average Tanzanian woman, for example, spends 8 h/day, or 56 h/week gathering fuelwood. Many Senegalese women spend roughly 4–5 h/day, or 35 h/week in search of fuel. On average, Kenyan women spend 3.5 h/day.[33]

This time and labor spent walking, searching for, and carrying biomass fuel is taken at the expense of education, productive farming or wage income, and child care. If an SBC were used according to estimates that SBCs save roughly half of conventional fuels, we could approximate that women could save half of the time that they spend in gathering fuel. Indeed, because of the labor-free nature of solar cooking itself—which requires only a few rotations of the oven during the cooking process of several hours—women would save additional time. Solar cooking is typically performed by putting food in to cook in the morning, and simply removing it around the main afternoon mealtime. Foods do not burn and thus require little monitoring. Furthermore, solar cookers are safe and the rotations could be performed by young children. The time saved could allow women to attend school, to spend more time in household food farming, to undertake business ventures or wage employment that could contribute to the household income, and to take better care of the health and well-being of children. Since education, health, and child welfare comprise the factors of human capital, the solar cooker could contribute directly to long-term economic development and higher standards of living.

Indeed, if we view domestic unpaid work as part of a country's GNP, we can see SBCs as an increase in the capital stock per worker. Increases in capital per worker constitute increases in output per worker, which translates to economic growth:

$$\Delta Y/Y = [(1\text{-}\theta) \times \Delta L/L] + (\theta \times \Delta K/K) + \Delta A/A \quad \text{or}: y = f(k)$$

where $1-\theta$ and θ represent the factor shares of labor and capital respectively, A is overall technological change that affects production, Y is national income, and k and y represent capital and output per worker respectively.

Finally, with its contributions towards women's and children's welfare, an SBC can have a positive impact on population growth rate reduction, thereby allowing African economies to avoid the low-level equilibrium trap. As one study described, solar cookers invariably improve the health of children.[34] Indoor air pollution from conventional cooking fires and stoves contribute to acute respiratory infection (ARI), which is the leading health hazard to children in developing countries, causing about 4.3 million deaths per year. With solar cookers, this pollution is virtually eliminated, reducing the risk substantially for ARI and child mortality. As fertility rates decline due to fewer child deaths, population growth slows and per capita income increases.

CONCLUSION

SBCs demonstrate the ways in which grassroots action can contribute to meaningful economic growth and development. Through such a democratic participatory model, equitable, sustainable development can occur. The large-scale, centralized programs have had limited success in improving the lives of Africans, in part due to mismanagement, and in part due to external manipulation. Grassroots development, however, evades the usual bureaucratic trappings, and places development directly in the hands of its proclaimed beneficiaries. Appropriate technology based on improving the lives of the masses underscores fundamental premises of development: good quality of life for all. It also demonstrates the possibilities for self-reliance, and the ability of non-experts to manage their own technology, and moreover, their own communities. Solar box cookers provide one strategy for such a non-paternalist development that will usher in the 21st century.

However, crucial to the successful dissemination of SBCs is not only their economic practical value but also their socio-cultural viability. In formulating programs, it is first necessary to consider the vast environmental and cultural diversity within sub-Saharan Africa. As is required of any firm attempting to be competitive, SBC dissemination programs must cater to the specific needs and wants of their customers, the energy consumers. This includes understanding the cooking habits, the cultural practices, the power relations, and social structure of the community involved, as well as the larger geo-political forces which impact the people of that community. Because SBCs potentially benefit a traditionally disempowered group, women, gender relations and power within the household must be especially considered. In most areas of sub-Saharan Africa, new technology is considered a male realm and subject to men's control. Like other new devices perceived as embracing a more advanced technology, SBCs have become underutilized in some areas where male heads of households refuse to let their wives or daughters use the cookers.[35] Clearly, the success of dissemination and, moreover, continued use, involves a more complex picture than offered by the individual rationality tenets of neo-classical economic theory.

Finally, the case of SBCs illustrates the necessity for a re-valuation of traditional economic measures. The negative externalities that result from deforestation surface within the economics of rural and poor urban African households. The cost of environmental degradation must be considered in national income accounting, as natural resources provide an essential source of livelihood for current and future generations. Furthermore, national accounting measures must evolve to effectively portray economic activity by incorporating domestic unpaid work as production. SBCs illustrate how reducing domestic workloads contributes to overall productivity gains through the development of human capital and through time allowance for income-generating activities. In this sense, domestic work is an

integral part of economic activity within a nation. With these factors considered in national accounting, African and other developing countries can achieve equitable, meaningful development that can be enjoyed by future generations.

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Appendix 1. Cost and efficiency of alternative cooking technologies, 1991

	Efficiency		
	Stove (%)	System (%)	Stove Cost US$
Stoves			
Traditional			
Dung	11–15	10–14	0.00
Agric. Residues	13–17	12–16	0.00
Wood	15–19	14–18	0.00
Commercial Wood	15–19	14–18	0.00
Charcoal	19–23	8–12	3.00
Improved biomass			
Wood	27–32	26–31	6.00
Charcoal	29–34	13–17	8.00
Wood II	40–44	38–42	10.00
Liquid			
Kerosene wick	40–45	36–41	20.00
Kerosene pressure	45–50	41–45	40.00
Alcohol wick	40–45	33–37	20.00
Alcohol pressure	45–50	37–42	40.00
Gas			
Central gasifier	55–60	39–42	20.00
Site gasifier	40–45	39–44	50.00
Biogas	55–60	54–59	20.00[a]
LPG	55–60	48–53	50.00
Natural gas	55–60	53–58	20.00
Electric			
Resistance	60–65	17–21	75.00
Microwave	55–60	16–20	250.00
Solar			
Solar box oven	25–30	25–30	25.00

Source: U.S. Congress, Office of Technology Assessment (OTA) Fueling Development: Energy Technology for Developing Countries (OTA, Washington D.C., 1992, 296).
Note: The fuel system demands significant capital and extensive labor for collecting and inserting biomass and dung.